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Analysis of Dynamic Loading to the Head-Neck

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INTRODUCTION

This study was conducted to develop a methodology for delivering axial dynamic tensile loads to the head-neck complex of human surrogates. Accelerations at the center of gravity of the head, and the axial and shear forces and bending moments at the occipital condyles were derived.

METHODS

The experimental design consisted of testing post mortem human subjects (PMHS) and the 50^{th} percentile anthropomorphic Hybrid III dummy. The PMHS was placed on a laboratory-designed automotive type seat. It was positioned under the platform of a custom-designed electrohydraulic testing device. The Frankfort plane (line joining the auditory meatus and the inferior edge of the orbit) was held horizontal. Retroreflective targets were inserted into the bony elements of the cervical vertebrae. Pre-test radiographs were obtained to document the position of the targets.

Triaxial linear accelerometers were rigidly mounted to the anterior and posterior regions of the head, and to the left and right mastoid processes. Triaxial angular velocity sensors were also rigidly fixed to the head at the anterior and posterior regions. The specimen was distracted in the axial direction using the piston of the electrohydraulic testing device at a velocity of 8.0 m/sec. Tensile load and distraction data were gathered using the built-in uniaxial load cell and linear variable differential transformer (LVDT). In addition, a uniaxial accelerometer was mounted in-series with the piston.

All sensor data were digitally acquired at a sampling frequency of 12,500 Hz, according to the Society of Automotive Engineers specifications. The dynamic loading sequence was photographed using a high-speed video camera operating at 1000 frames per second. Following unloading, a radiograph of the specimen in the lateral projection was taken to capture the head-neck complex anatomy. In addition, computed tomography (CT) scans of the head-neck complex were obtained in the sagittal plane. Cryomicrotomy images were obtained at 1.00 mm intervals using a heavy-duty cryomicrotome. Pre- and posttest radiographs coupled with CT and cryomicrotomy were used to determine the integrity of the head-neck complex following axial tensile loading. A schematic of the test setup along with the instrumentation is shown in figure 1.

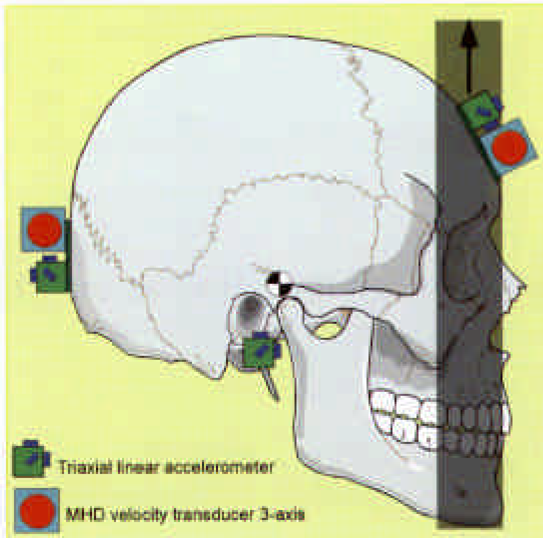

Figure 1. Schematic of the test setup. Vertical arrow indicates the direction of the tensile force application.

The Hybrid III anthropomorphic device was tested in a similar manner. The dummy head-neck was mounted to the platform of the electrohydraulic testing device, and the head was distracted using the piston. For loading purposes, a cable attached to the chin of the dummy was connected to the piston. Instrumentation consisted of triaxial linear accelerometers and triaxial angular velocity sensors on the head and the uniaxial load cell and LVDT on the piston. A schematic of the test setup is shown in figure 2.

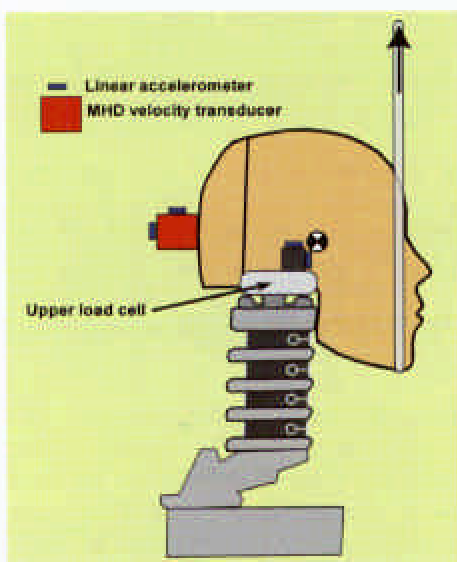

Figure 2. Schematic of the test setup with the head-neck of the Hybrid III dummy. Vertical arrow indicates the direction of the dynamic tensile force. A cable was attached to the chin to facilitate axial tensile loading of the dummy.

Data analysis included filtering all accelerometer signals and angular velocity sensor signals at SAE class 1000. Linear triaxial accelerations were computed at the center of gravity of the head using standard equations of equilibrium. Accelerations at the center of gravity of the head were computed using different combinations of data from the multiple sensors used to instrument the surrogate. The external piston force was compensated for inertial effects using the uniaxial accelerometer data. The compensated force was filtered at SAE class 600. Angular velocity data from MHD sensors were used to compute head angulations as a function of time. These data were used to compute the axial and shear forces and bending moments as a function of time. Moment data were filtered at SAE class 600. As before, forces and moments were computed using different combinations of data from multiple sensors.

RESULTS AND DISCUSSION

Dynamic loading by the electrohydraulic piston distracted the head-neck complex without significant off-axis forces or moments. The kinematics captured by the high-speed video photographs confirmed axial motion. Computed accelerations at the center of gravity of the head ranged from -50 to -60 g in the x, from -10 to -20 g in the y, and from -60 to -70 g in the z direction. Data computed using different sensor combinations are included in figure 3 for comparison. A reasonably good match in the peak acceleration data and the pattern of the acceleration-time history can be discerned from these plots. Peak axial forces ranged from 2500 to 3500 N, shear forces ranged from 500 to 2500 N; maximum extension bending moments ranged from 40 to 80 Nm. Time-history plots of the axial and shear forces and bending moments are included in figure 4. Similar to the case of head accelerations, patterns of these data followed the same trend and peaks of individual metrics occured at similar times. Image evaluations indicated distractions at the atlanto-axial level of the cervical spine with no accompanying bony fractures. This was confirmed by cryomicrotomy.

The kinematics of the Hybrid III dummy head-neck was such that the cable positioned to distract the dummy pulled away from the chin after applying the dynamic load. Following this event, the head-neck of the dummy underwent extension. This was confirmed by the high-speed video images. Digital data from the Hybrid III dummy were also processed in a similar manner. Because of the availability of a load cell and a triaxial accelerometer at the center of gravity of the head of the dummy, it was possible to compare the computed accelerations and forces and moments at the occipital condyles with measured data. Plots of these data are shown in figures 5 and 6. As in the case of the PMHS experiment, patterns of the acceleration and forces and moments were similar. However, the magnitudes of these parameters were different between the two surrogates.

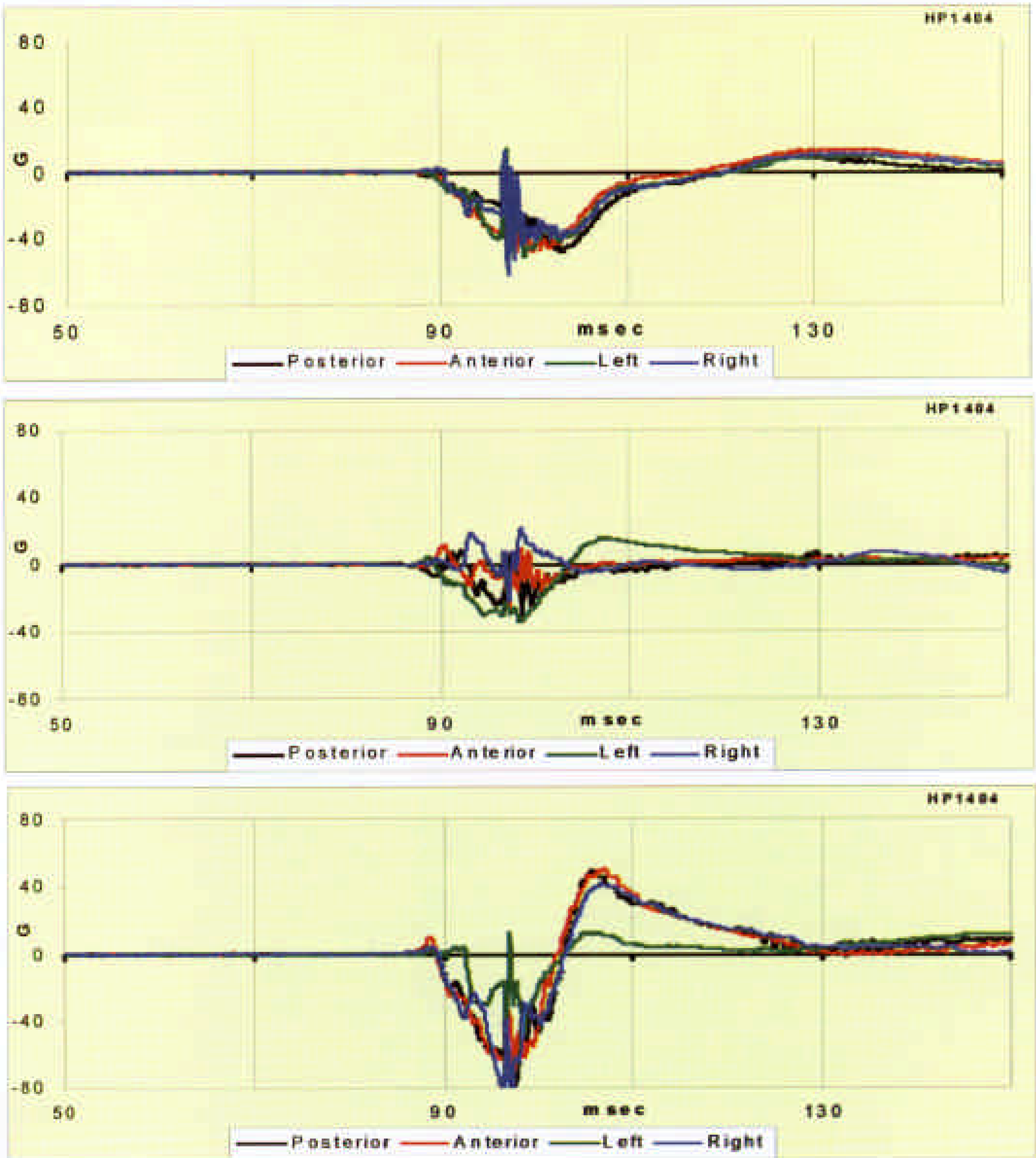

Figure 3. Plots of accelerations at the center of gravity of the head (x-top, y-middle, z-bottom) computed using different combinations of sensor data. See legend for details. (Curves in lack represent data from the posterior accelerometer, red represents data from the anterior accelerometer, green represents the left mastoid accelerometer, and blue represents the right mastoid accelerometer.)

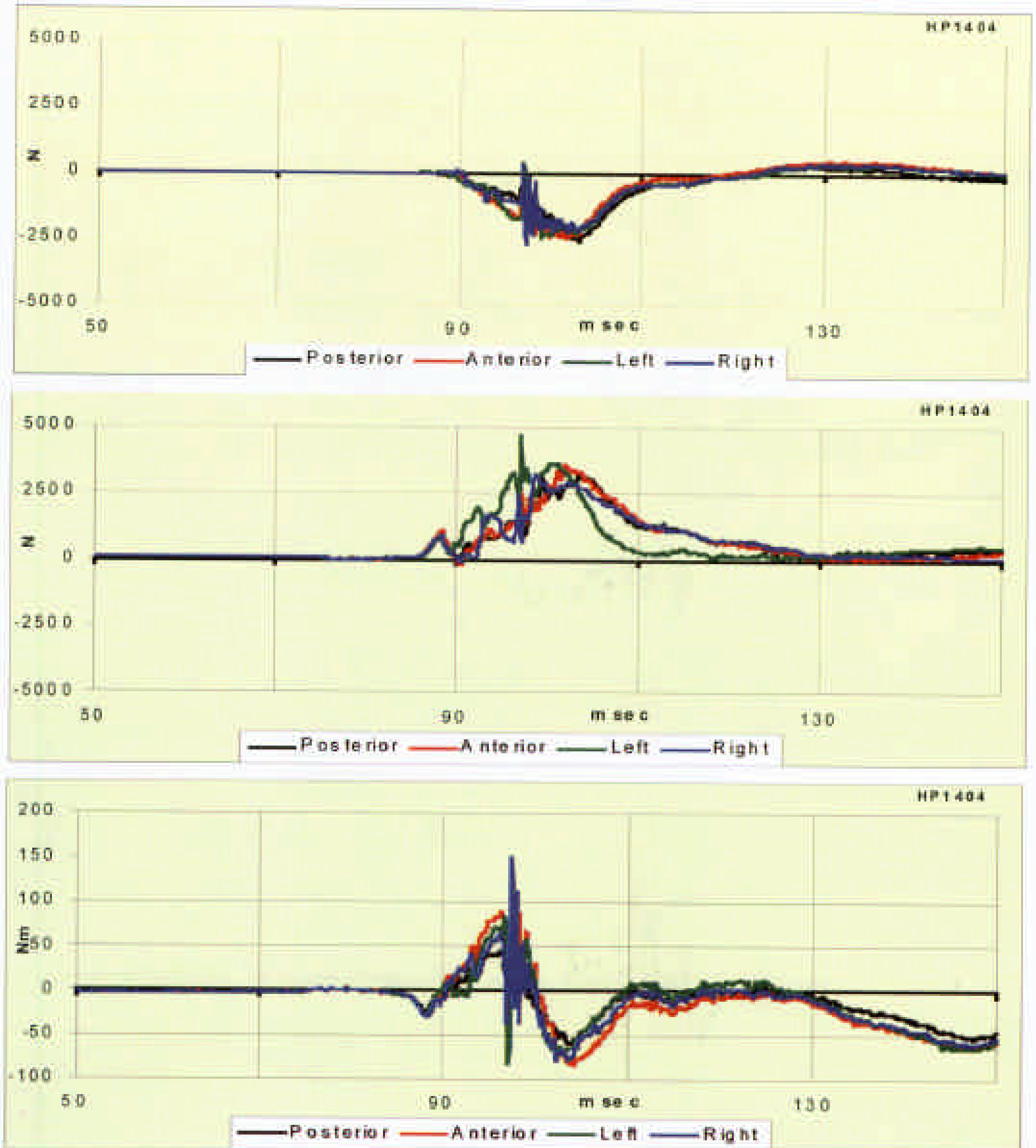

Figure 4. Plots of forces (x-top, z-middle) and moments (bottom) at the occipital condyles computed using different combinations of sensor data. See legend for details. . (Curves in black represent data from the posterior accelerometer, red represents data from the anterior accelerometer, green represents the left mastoid accelerometer, and blue represents the right mastoid accelerometer.)

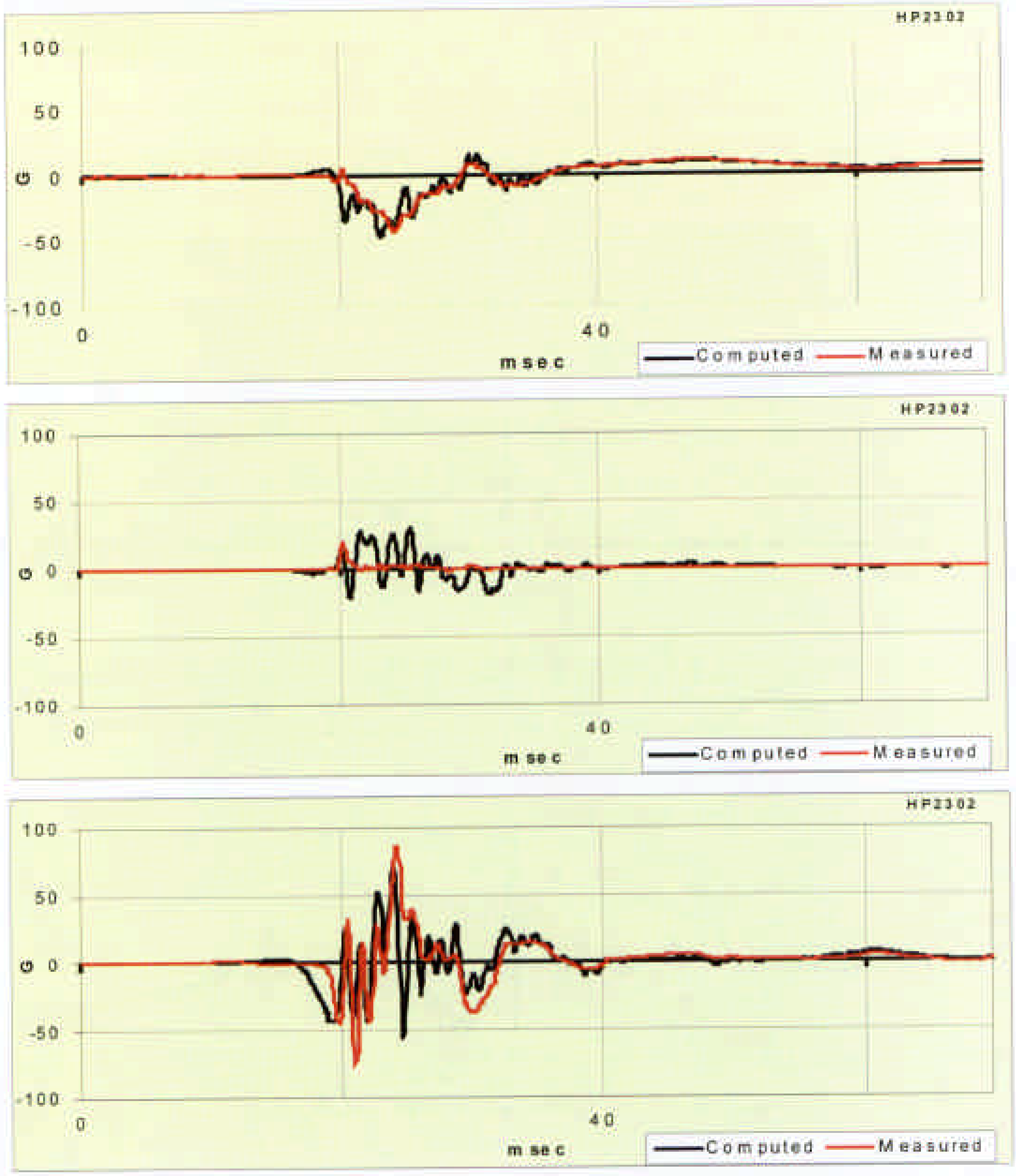

Figure 5. Plots of accelerations at the center of gravity of the head (x-top, y-middle, z-bottom) computed using sensor data and compared with data recorded from the sensor inside the head of the dummy.

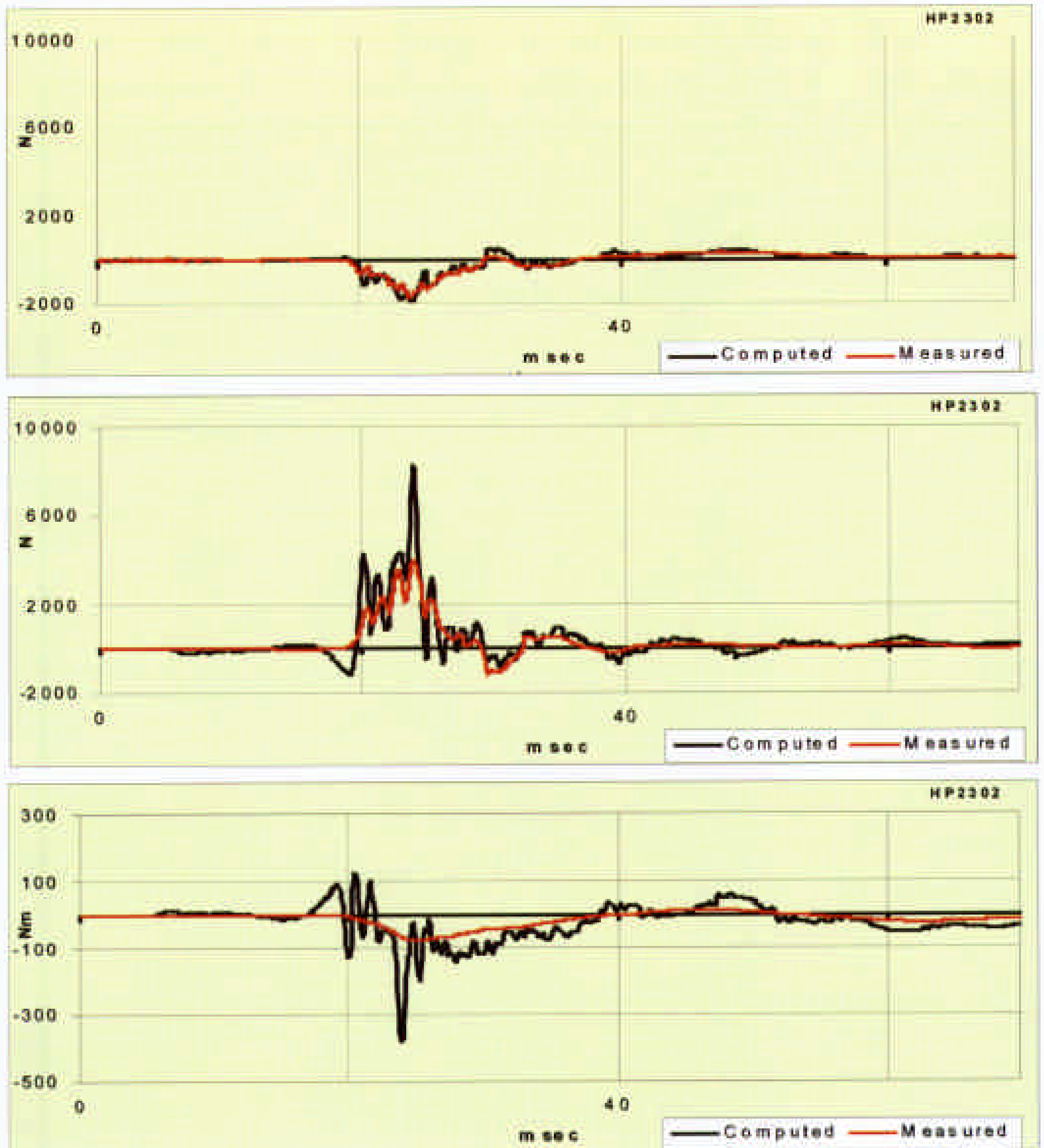

Figure 6. Plots of forces (x-top, z-middle) and moments (bottom) at the occipital condyles. See legend for details. Computed variables using sensor data (black curve) are compared with data obtained from the six-axis load cell (red curve) inside the head of the dummy.

These experiments show that it is possible to conduct dynamic loading tests using PMHS by applying the distraction force through the chin of the surrogate. Further, the instrumentation used in the testing protocol demonstrates promise in computing accelerations at the center of gravity of the head, which in turn, can be used to derive forces and moments at the occipital condyles of the head-neck complex. Although not reported in this paper, high-speed digital video photography will assist in quantifying the motions of the cervical vertebrae as a function of the applied dynamic load. Correlations of the kinematics with the forces and moments will be of value in determining human tolerance under these forces. In addition, a comparative evaluation of these data with similar results from the dummy can be used to assess biofidelity. Additional experiments are planned to achieve these goals.

ACKNOWLEDGEMENT

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DISCUSSION

PAPER: **Analysis of Dynamic Loading to the Head-Neck**

PRESENTER: ***Michael Schlick, Medical College of Wisconsin***

QUESTION: *Guy Nusholtz, Daimler Chrysler*

I have a number of comments and observations. One is you're using different filter classes when you're comparing similar data. I need to know that's what SAE recommends. If you're going to use the accelerations to predict the forces you should keep the same filter frequency so you don't have an artifact due to the fact you're using different filters.

ANSWER: Okay. Thank you.

Q: The other comment is, it looked like you had uncorrelated noise in one of your signals and you might even want to bring the filter down just to see what it looks like when you get rid of your uncorrelated noise?

A: Throughout the process a variety of different filters have been used. And my comment was, yes, if we filter everything down to DC everything matches perfectly. But I wanted to avoid that and try and keep some of the frequency content that we're actually measuring. Are you saying though that we're measuring noise that isn't there?

Q: In some cases it looked like you had uncorrelated noise. I mean it is hard to tell because I am not looking at all the data, but if you compare one signal to the other, one signal is relatively smooth.

A: Yes.

Q: And the other oscillates kind of around that but sometimes it's a little above, sometimes it's a little below. And those oscillations contaminate your ability to extract useful information or make the comparison. So, if your fundamental response is of a very low frequency then you should find what that frequency is, where you maximum information content is, and then filter the signal you're using to predict it at that frequency so you'll end up with a closer relationship to the two signals.

A: Okay. Thank you.

Q: Have you actually gotten any data comparing the results from the Hybrid III to the post-mortem?

A: No, because if you recall, the Hybrid III is a little bit hard to interpret from the calculated results. In other words, you can see there's a general morphology here, but there is some noise spikes that give you some alarming numbers. So, trying to find out whether moment leads or forced leads and things like that between the Hybrid III and the post-mortem human surrogate, it is a little bit hard to determine. And also to look at which force you use. Obviously, I did not in the human surrogate I didn't get any forces in the 6,000 to 8,000 Newton range, but I don't know whether that's indicative of this Hybrid III or whether that's an erroneous observation because of the calculation.

Q: Those are awful short time durations on those spikes.

A: Yes.

Q: So, I guess you've got another task because you have to figure out whether that's noise or not or whether it is just an artifact of the dummy. The dummy just may produce spikes which are not real or not necessarily, they're real, but produce a spike which you don't ever see in a live human.

A: Okay.

Q: *Jeff Crandall, University of Virginia*

I just had a question on the interpretation of the forces and moments at the OCC One location. That is actually including all the skin and musculature, is that correct? So it would be sort of an equivalent of what you would have for a combined effect in the Hybrid III but it is not really what would be going into the ligamentous cervical spine?

A: I'm not entirely clear on your question. We did use full whole intact cadavers. We had a minimally invasive incision we made laterally to put targets in, but otherwise we tried to keep the cervical spine as intact as possible. Now, how that compares to the dummy, are you speaking of neck shrouds or things like that?

Q: No. I am just saying that the forces and moments are shared by the musculature in the skin and not only the ligamentous cervical spine. So it is just a question in terms of what you call those forces and moments and where they're located. The head would be the equivalent of what you compare to the Hybrid III.

A: I understand. You're right. We do have multiple load paths you're saying in the post-mortem human surrogate obviously. I guess, initially, we were anticipating that the injury would be closer to the bony elements and that's why the calculations were made to there. And, classically, they're made there because of the Hybrid III for comparison. But you're right, the injury may exist elsewhere.

Q: *Mark Haffner, NHTSA*

I just have a quick question on the instrumentation and specifically the angular accelerometer. At the end you suggested that perhaps the bandwidth issue might be a concern. And I was just wondering what led you to that conclusion and also whether, just generally, what kind of experience you're having with that instrument and maybe you could identify the instrument that you're using?

A: I am using an ATA MHD style angular rate transducer and in some cases a Triax, referred to as a Dynacube.

Q: That's the angular velocity.

A: I am sorry. Angular velocity transducer. We used one 7302 Entran angular accelerometer which has a slightly higher frequency content. And as Dr. Nusholtz pointed out, these are some short time durations, he was referring to some of the spikes. But if you look at this time duration also, it is considerably shorter in the Hybrid III compared to the post-mortem human surrogate. That is an issue. We were planning on running some of those filters wide open, so to speak, up at class 1,000 and then tightening the linear accelerations and seeing it at 180 or 600 and seeing if there wasn't a better match.

Back to your original question, we did a quick power spectrum of the linear accelerometers mounted to the Hybrid III skull exteriorly and mounted to the cadaver skull and we found that as the frequency diminished on the Hybrid III, the event wasn't even beginning on the cadaver. That's preliminary and a very brief analysis on what we've done on the frequency of the device. But we're not convinced that's it, we just know specification-wise that they are listed as a slower or lower frequency transducer.

Q: Right. Are you seeing any artifacts in the angular accelerometer, the 7302?

A: It's a little bit noisier signal, but the one instance and the few times I actually looked at that data it seemed to compare quite well actually in the post-mortem human surrogate. I haven't used it in the Hybrid III yet so I have no comment on that situation.